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DESIGN AND DEVELOPMENT OF AN IOT-ENABLED SMART SAFETY MASK FOR REAL-TIME HAZARDOUS GAS AND RADIATION MONITORING IN GARBAGE DUMP WORKERS

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DESIGN AND DEVELOPMENT OF AN IOT-ENABLED SMART SAFETY MASK FOR REAL-TIME HAZARDOUS GAS AND RADIATION MONITORING IN GARBAGE DUMP WORKERS

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Abstract: Workers at landfills have serious occupational risks due to gases emitted from the anaerobic degradation of waste, such as methane (CH_4) and hydrogen sulfide (H_2S), and potential exposure to ionizing radiation from poorly discarded radioactive materials [6][7]. Particle filtering masks do not detect or alert for gas hazards, rather they simply provide protection from particulate emissions. This paper develops a low-cost smart safety mask using an Internet of Things (IoT), wearable platform with an ESP32 microcontroller containing an MQ-2 gas sensor for methane detection and a Geiger-Müller tube for radiation detection. Gas and radiation data are sent wirelessly to a Blynk IoT dashboard and can be accessed and monitored in real-time by Work Supervisors on their mobile devices. A buzzer is activated if either the Methane concentration exceeds 10,000 ppm or if the Radiation dose rate exceeds 0.8 μSv/hr; the buzzer will operate independent of network connectivity. Preliminary prototype testing has demonstrated the adequacy of gas and radiation sensors, threshold detection at the set point, and the ability of the system to remotely alert to workplace hazards. There is currently no low-cost, wearable solution that combines gas detection, radiation detection, local alerting capabilities or IoT connectivity that is appropriate for landfill workers – this indicates a significant gap in the existing literature regarding the safety of workers in the landfill environment [1][2][3]. This system supports United Nations Sustainable Development Goals (SDG) 3, 8, 11, and 12.

Keywords: IoT; ESP32; MQ-2; Methane Detection; Geiger-Müller Tube; Radiation Monitoring; Smart Mask; Landfill Safety; Blynk; PPE; Occupational Health

I. Introduction

Hazardous gases such as methane, carbon dioxide, hydrogen sulfide and ammonia continuously occur during the decomposition of a landfill [6][10]. Hydrogen sulphide is particularly hazardous in that it is colourless, rapidly leads to olfactory fatigue when present at higher concentrations and has contributed to the deaths of many workers worldwide [8]. Although methane is odourless like hydrogen sulphide, it poses an extreme risk of asphyxiation and explosion in poorly ventilated lands [6]. Aside from the chemical hazards thrown off by decomposing landfills, there is the risk of radiation exposure from illegally disposed of medical or industrial wastes that contain radioactive materials not addressed by typically worn personal protective equipment (PPEs) [13].

Most landfill site workers wear basic filtering facepieces to filter out particulate matter from their breathing air but do not have electrical or electronic devices attached to their facepieces to monitor the presence or absence of chemical agents [9][11]. Industrial grade gas detector systems are capable of detecting a range of hazardous gases, however they are very expensive and also require substantial infrastructure and are not suitable for individual worker use. The world's developing nations suffer the most from the gap in safety created by landfills, since they have very little enforcement of the laws and regulations protecting their workers making them very susceptible to personal injury [12].

The use of the Internet of Things (IoT) technology, such as low costs of Wi-Fi enabled microcontrollers like the ESP32 and low-cost MQ-series sensors, enables real time and networked environmental monitoring to be accomplished at a fraction of the cost of traditional methods [3][5][19]. Previous studies have successfully validated the ability of the ESP32 to provide gas monitoring with cloud connectivity as well as explored the use of smart masks in the literature [1][2]. Yet to date, there has not been a smart wearable device that can integrate gas detection, radiation monitoring, IoT connectivity, and on-device alerting in a single device designed specifically for landfill employees.

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II. Literature Review

A. Occupational Hazards in Landfill Environments

H_2S is one of the most dangerous components of landfill gas because it will give the worker a rapid loss of their ability to smell, therefore leaving them unaware of their surroundings when they are exposed to harmful levels of H_2S [8]. OSHA has documented 46 deaths of American workers resulting from the exposure to H_2S from 2011 to 2017 [8]. Methane is a similar asphyxiation and explosion hazard [6]. Workers are also at risk from illegally-landfilled medical and industrial radioactive waste being mixed with general municipal waste; there is no way to protect them or detect the presence of this waste using normally-available safety equipment [13][20]. In South Africa and Bangladesh, solid waste workers are documented to encounter a wide variety of occupational health hazards such as chemical exposure, physical injury, and biological hazards [9][11].

B. Wearable Safety Devices and Smart Masks

The growth of the miniaturization of electronics, along with developments in low-power microcontrollers and wireless communication protocols, have led to the rapid development of highly integrated PPE that includes sensors in the past 10 years [16][17]. Early versions of wearable safety equipment paid more attention to physiological parameters like heart rate and temperature than to gas sensors, with the latest research focussing on integrating environmental gas sensors into the respiratory PPE system [2].

Röning et al. proposed the most comprehensive smart mask framework to date, which consists of a platform that combines sensing technologies; materials science; artificial intelligence; wireless communication; and internet of things (IoT) infrastructure into one device. This transforms a mask from being a passive physical barrier to being an active, connected means of providing safety [2]. A validation study that was published in 2025 showed that a wearable smart mask based on a combination of the MQ-135, MQ-9, and DHT11 sensors connected to an ESP8266 microcontroller via the Blynk app could achieve multi-sensor detection and real-time cloud communication for industrial applications in a wearable format [1]. The design of this system was intended for the industrial environment, therefore it had no capability of measuring ionizing radiation.

Surveys conducted on the available wearables show the increased maturity in this industry, while reaffirming the very limited number of radiation-capable wearables available for non-nuclear workers [17][18]. At present, there are no documented wearables that combine gas and radiation sensing capabilities for landfill workers [13].

C. IoT-Based Gas Monitoring

Numerous studies confirm that the ESP32 paired with MQ-series sensors can be used to monitor air quality in real-time and connect to the cloud through either ThingSpeak or Blynk [3][4][5]. The work by Easterline et al. shows that the use of MQ-2, MQ-7, MQ-8 and MQ-135 sensors in an ESP32-based device was validated with full-day tests performed in a typical urban setting, with results demonstrating that these sensors meet acceptable ranges for error when compared to reference devices [3]. The research presented at ICMED-ICMPC 2023 demonstrated the validity of using MQ-2 and MQ-135 sensors in concert with threshold-based Blynk push notifications and confirmed that such capabilities are applicable to this architecture [4]. In addition, however, a recent publication from Jacko et al. confirmed that the ESP32 platform is a reliable IoT platform upon which to build production applications [19]. Collectively these studies demonstrate that the selected hardware and cloud platform together have been successfully utilized to monitor air quality in a similar manner in multiple studies.

D. Radiation Monitoring

Research shows that little has been published on the subject of wearable radiation monitoring for non-nuclear workers [13]. Geiger-Müller tubes are well-established, robust, and inexpensive detectors that can measure all three types of radiation (alpha, beta, and gamma) by counting the number of ionizations that occur when radiation passes through them and generates a pulse of electricity [14][15][20]. IoT-connected (Internet of Things) devices for radiation monitoring have been utilized in fixed applications; however, there are very few examples of them being used in wearable form [13]. The method proposed here uses an ESP32 to record the number of GM tube pulses per time period, convert those counts into corresponding dose rate estimates, and send alert notifications when dose rate thresholds are exceeded — the detection method is proven but being implemented in a wearable format for the first time here [14][20].

E. Gaps and Motivation

With a body of literature that identifies 4 primary shortcomings in IoT gas detection monitoring exists there is currently a gap where: 1) All existing IoT gas detection systems are not portable wearables; 2) There are no affordable portable wearables designed to detect gases and radiation combined; 3) Existing smart masks are designed for use in controlled industrial environments in developed countries but there is no research on smart masks for use outdoors in landfills in low resource environments; and 4) The concepts of using real-time cloud-based supervision of the worker for monitoring have not been tested on a wearable basis in an outdoor landfill. This proposed system seeks to fill all 4 gaps with one low-cost system.

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TABLE I

Comparative Analysis of Research Literature and Technological Prototypes

Ref	Study	Application	Platform	Sensors	Communication	Output / Alerts	Limitation vs. Proposed
[1]	IoT-Enabled Mask (2025)	Industrial (Coal/Plastic)	ESP8266	MQ-135, MQ-9, DHT11	Wi-Fi	Buzzer, Mobile Alerts	No radiation sensing; generic gas profile; not landfill-specific.
[2]	Smart Mask (2022)	Pandemic/Respiratory	ESP8266	HEPA filter, Airflow	Wi-Fi	LED, Mobile Alerts	Focused on viral protection; lacks gas and radiation detection
[3]	Smart Air Monitoring (2024)	Urban air quality	ESP32	MQ-2, 7, 8, 135	Wi-Fi	Cloud Dashboard	Stationary/Non-wearable; no radiation; no landfill context.
[4]	Hazardous Gas (2023)	Household/Industrial	ESP32	MQ-2, MQ-135	Wi-Fi	Blynk, LCD Display	Fixed installation; lacks radiation monitoring and portability.
[5]	IoT Health & Safety (2020)	Industrial workers	NodeMCU	MQ-135, MQ-2	Wi-Fi	App notifications	No H2S monitoring; lacks radiation coverage; high cost.
[6]	Landfill Gas Primer (2001)	Hazard documentation	N/A	CH4, H2S, CO2 (Ref)	N/A	Regulatory guides	Documentation only; provides no engineering/IoT solution.
[7]	NY Health Dept (2021)	Community health	N/A	H2S, NH3 (Ref)	N/A	Policy reference	No hardware device; focused on manual monitoring/policy.
[8]	OSHA Guide	Occupational H2S safety	N/A	H2S (Reference)	N/A	Safety standards	Reference only; lacks real-time detection or radiation safety.
[9]	Tshivhase et al. (2022)	Waste handlers (S. Africa)	N/A	Physical/Bio hazards	N/A	Qualitative study	Identifies gaps but offers no technical wearable solution.
[10]	Siddiqua et al. (2022)	Global landfill health	N/A	Env. Pollutants	N/A	Impact analysis	Theoretical review; no wearable or monitoring hardware.
[11]	Informal Waste Risks (2025)	Open disposal (Khulna)	N/A	Occupational risks	N/A	Vulnerability Map	Socio-technical study; no integrated sensor hardware.
[12]	MSW Health Impact (2024)	Waste mismanagement	N/A	Bio-markers	N/A	Health Review	Validates risk; no engineering monitoring solution.
[13]	Radiation & IoT (2021)	Non-nuclear env.	IoT Base	Ionizing Radiation	Varied	Cloud data	Primarily fixed installations; limited wearable integration.
[14]	Portable Dose Detector (2017)	Radiation monitoring	MCU	Double GM Tube	N/A	Digital LCD	Portable but not wearable; lacks gas detection and IoT sync.
[15]	Gamma Prototype (2025)	Radiation detection	MCU	GM Tube	N/A	Local detection	Lacks mask integration, gas sensors, and wireless sync.
[16]	Industrial Wearable (2019)	Industrial safety	MCU	IMU, Env. Sensors	Wi-Fi	Local/Remote	Generic; no specific radiation or landfill gas focus.
[17]	Wearables Survey (2021)	Work safety survey	Various	Heart rate, Gas, IMU	Multi	Dashboards	Notes lack of low-cost, integrated gas/radiation units.
[18]	Lone Worker System (2021)	Safety monitoring	MCU	GPS, Fall detection	GSM	SMS / Cloud	Focuses on location; lacks gas/rad sensing capabilities.
[19]	ESP32 implementation (2023)	IoT device design	ESP32	Technical Benchmarks	Wi-Fi	Validation data	Technical platform validation only; no safety application.
[20]	Low-cost GM Tube (2019)	Personal protection	MCU	Energy-Comp. GM	N/A	Local dose rate	Focuses on radiation only; no gas or mask integration.
Prop	IoT Smart Safety Mask	Landfill Workers	ESP32	MQ-2 + GM Tube	Blynk	Buzzer + App	Combines gas + radiation; wearable; landfill-specific; low-cost

III. Methodology

A. System Overview

This system operates according to a three-tier design: sensing, processing, and wireless transmission. An MQ-2 gas sensor will continuously monitor the concentration of methane gas, whereas a Geiger-Mueller (GM) tube will monitor for ionizing radiation. Data from the sensors will be processed through an ESP32 microcontroller that will compare the current sensor values against preset safety thresholds; if any of the threshold safety values are exceeded, the microcontroller will activate a buzzer within the ESP32 device. At the same time, the information from both of the sensors will be sent to the Blynk Cloud, allowing supervisors to observe their workers in real time via mobile dashboards [4][5].

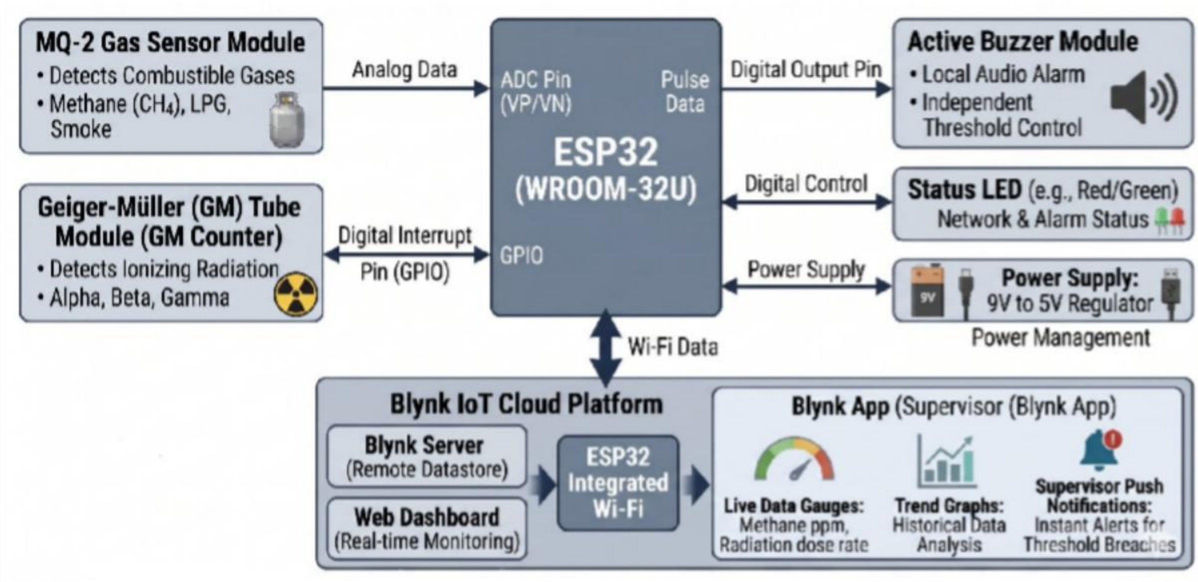

Fig. 1. System Block Diagram

B. Hardware Components

The microcontroller integrated into the project is an ESP32 microcontroller as a central processing unit. The ESP32 was selected because of its capabilities to integrate both a Wi-Fi and Bluetooth chipset together, its low

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power usage, and affordability [19]. The MQ-2 gas sensor utilizes chemical resistive methods to detect methane and other combustible gases; the analog output from the MQ-2 is fed directly into the ADC of the ESP32, with the ADC converting the voltage to parts per million (ppm) by using a calibration curve provided in the MQ-2 datasheet [3]. In comparison, the GM tube detects all forms of radiation (alpha, beta, gamma) and creates an electrical pulse for each ionization event it detects; the ESP32 counts the number of pulses it receives over a predetermined time period, and then converts that to a CPM (counts per minute) and then generates a dose rate in µSv/hr [2][14]. The system has an active buzzer to provide a local warning, regardless of network connectivity, and the power source is a 9V battery that provides total portability for the entire device.

C. Software and Firmware Design

In the Arduino IDE, the firmware is created. The MQ-2 ADC output is continuously read by the main loop, which converts these readings into methane ppm based on a resistance-to-concentration mapping that was done prior [3]. Pulse count information from the GM tube is retrieved from an interrupt handler and converted into a dose rate at the same time as methane ppm are being processed. A buzzer is triggered anytime that the level of methane exceeds 10,000 ppm or the level of radiation exceeds 0.8 µSv/hr, and it will continue to sound until both levels have returned to safe limits. All threshold values are firmware constants that can be modified without changing codebase structure [6][7]. Finally, sensor readings will be pushed to Blynk via Blynk.virtualWrite() every set interval.

D. IoT Integration and Remote Monitoring

Using a single authentication token the ESP32 connects to the Blynk cloud through Wi-Fi and pushes periodic data on methane and radiation levels into unique assigned virtual pins [4]. The data is visible to the supervisor via real-time gauge and graph widgets on the Blynk mobile app. If either threshold has been reached, then the Blynk platform will automatically send push notifications to every supervisor device that is registered. This dual-alert architecture (local buzzer at the worker level, push notification at the supervisor level) allows for more timely and coordinated emergency response than either system could provide individually [1][4].

E. System Workflow

When powered on, the ESP32 initializes sensor interfaces, connects to Wi-Fi, and authenticates with the Blynk Cloud. The ESP32 will then enter continuous monitoring mode where it will read both sensors at set intervals and compare each reading to its threshold. If both sensors read within their thresholds, this data will be sent to the Blynk Dashboard; if either of the two sensors read over its threshold this will activate both the buzzer, and send a push notification to the user in real-time. The buzzer will automatically deactivate when both sensors return to a safe state to avoid alarm fatigue [1][4].

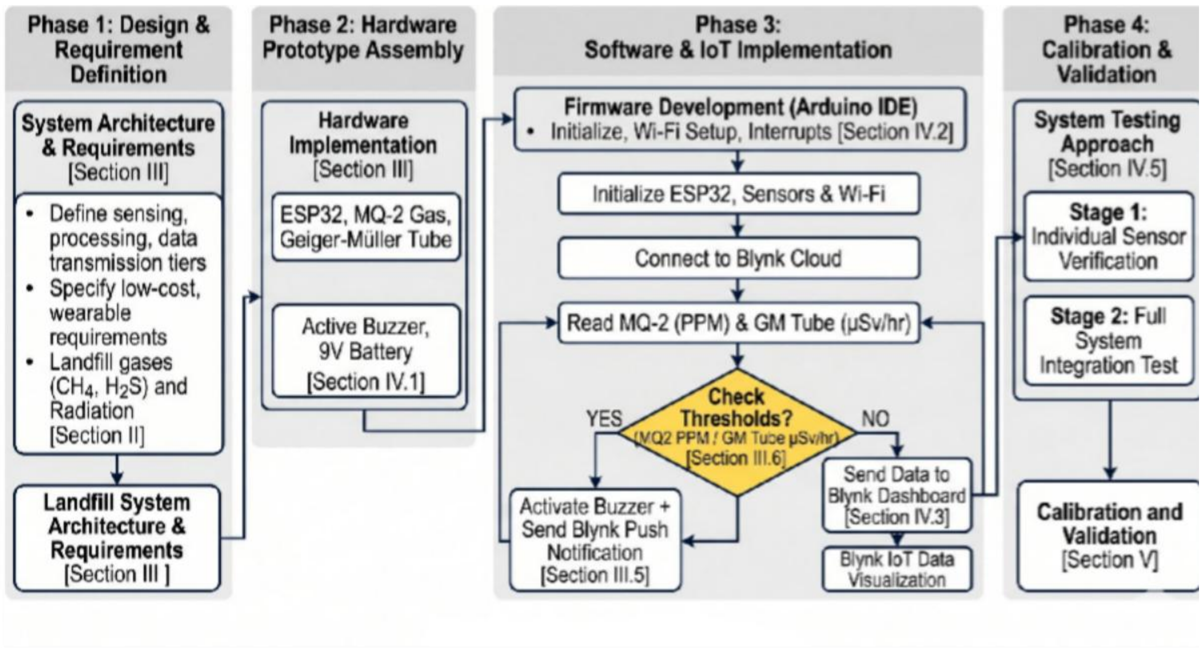

Fig. 2. System Workflow Diagram

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F. Safety Threshold Justification

The 10,000 ppm methane level corresponds to 10% of methane's LEL (lower explosive limit)—a common early warning level according to safety standards so that workers will have time to exit before a flame convulsion or asphyxiation occurs, which are both risks associated with high levels of methane [7][8]. The 0.8 μSv/hr radiation threshold is based upon the ICRP radiological protection recommendations and represents a conservative actionable level that is well above natural background levels of radiation (0.10–0.30 μSv/hr) and avoids excessive false positives due to normal background changes in the environment [8][9].

IV. Implementation

A. Hardware Assembly

The analog output of the MQ-2 sensor is connected to an ESP32 GPIO pin that also serves as an ADC input (5V). A GM tube is connected to a GPIO pin that is capable of generating interrupts, and the ESP32 uses interrupts to count ionizing pulses from the GM tube [2]. An active buzzer is powered by a GPIO pin in a HIGH state when in alarm mode, and a LOW state when in normal operation [1]. The entire circuit is powered by a 9V battery through the VIN pin on the ESP32, and converted to the proper operating voltage by the onboard voltage regulator of the ESP32.

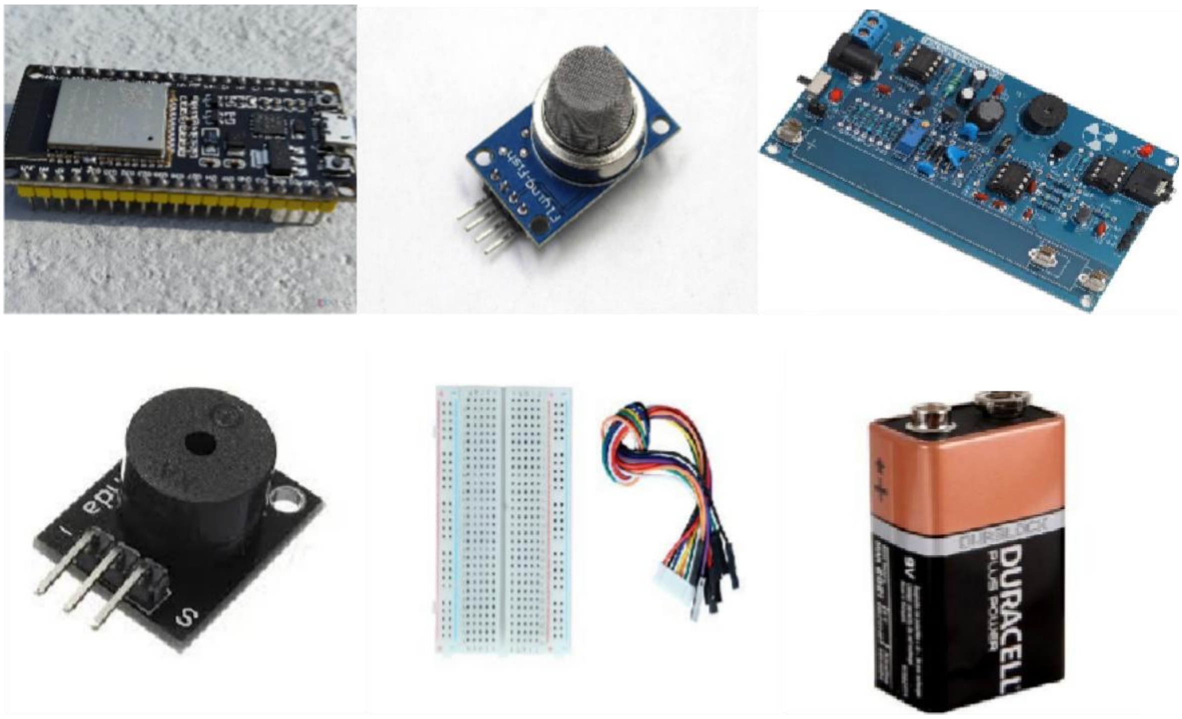

Fig. 3a. Images of Hardware Used

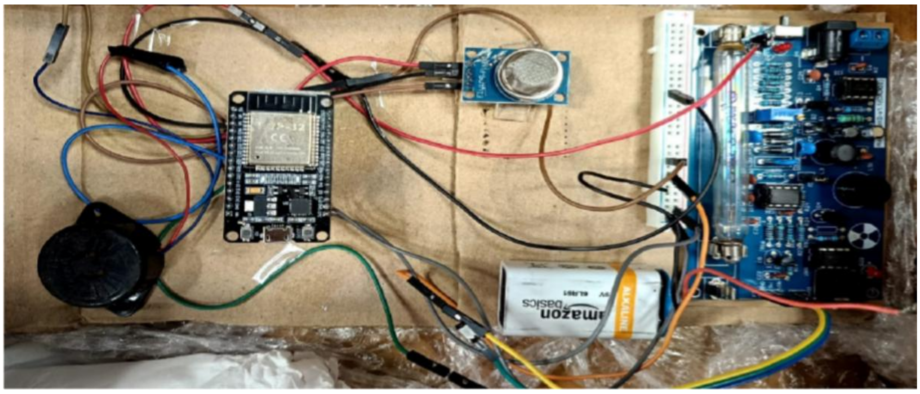

Fig. 3b. Images of Hardware Used

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B. Firmware Implementation

The purpose of the firmware is to initialize the serial debugging port, configure the GPIO pins, set up an interrupt on the GM tube pulse input pin to catch any pulses from the GM tube that may occur between loops, and call the method Blynk.begin() to connect to the cloud [4][5]. The main loop will use the ADC from the MQ-2 to read values, convert them to the corresponding PPM using the manufacturer's resistance-concentration curve, retrieve and clear the pulse count from the GM tube, and use the fixed conversion factor to convert that to μSv/hr [2][3]. The main loop will also compare the value of the constant to the threshold and determine if the buzzer should be turned on or off. Each time the main loop is executed, it will use Blynk.virtualWrite() to send the updated values to the dashboard [4].

C. Blynk Dashboard Configuration

The Blynk console connects the ESP32 to the project using an authentication token. There are two gauge widgets showing real-time methane (PPM) and radiation (μSv/hr) based on virtual pin mapping [4]. Any time the threshold is exceeded for either of the two parameters, the push notification automation rules will trigger and send a push notification regarding the parameter and how much it exceeded its threshold for supervisors to quickly evaluate severity prior to opening the complete dashboard [1][2].

Fig. 4, the Blynk dashboard widgets updated

D. Sensor Calibration

As part of our MQ-2 sensor calibration process, we take a baseline (R0) resistance measurement of the sensor in fresh air at 20 to 30 seconds after power on, then use the Rs/R0 ratio and manufacturers' sensitivity curves to calculate gas concentrations in parts per million (ppm) [3]. The firmware will store R0 value values, and they will serve as the basis (reference) for all subsequent measurements. The GM Tube only requires calibration in the sense that the on-board signal processing provides a clean digital output, but does not require a field calibration since the data sheet provides a constant CPM-to-μSv/hr conversion rate that is used directly in the firmware [2][7].

E. System Testing Approach

All testing involved a "two-step" verification process. The first step was to test each individual sensor using the Arduino IDE serial monitor to verify MQ-2 sensor response with controlled exposure to combustible gases and to verify GM tube operation through logical counts of the number of pulses it produced and by expected background dose rates [3][5][2][7]. The second step was to verify overall system functionality with buzzer activation upon detect of threshold breach; real time system updates through the Blynk dashboard; and push notice delivery times within acceptable limits [4]. The next phase of testing will take place at an operational landfill for final field validation.

V. Results and Discussion

A. Prototype Status

All the pieces were built; every piece of hardware was connected and tested individually. Every piece of firmware was operational, including the firmware to read sensors, establish a threshold to evaluate what the sensors read, activate the buzzer upon detection of a threshold, and operate in conjunction with Blynk. The Blynk mobile dashboard was set up with live sensor widgets and the ability to send notifications to a supervisor's device when the threshold is exceeded.

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B. MQ-2 Sensor Verification

The MQ-2 stabilized within 20-30 seconds after powering-up, consistently reading well below 10,000 PPM over the typical indoor ambient environment, confirming that the ADC-to-PPM calibration was valid. A controlled exposure to combustible gas produced a defined increase on the PPM level and the threshold detection activated the buzzer with no false activations experienced.

C. GM Tube Verification

Under ambient lab conditions the GM Tube was able to accurately detect and count radiation pulses and return dose rate readings consistent with expected background radiation levels of 0.10-0.30uSv/h. The pulse count algorithm, CPM conversion, and interrupt processing logic were all correct, with no false positive results and dose rate readings remained below the 0.80uSv/h alert threshold.

D. Alert System Verification

The onboard buzzer immediately activated upon detection of a simulated threshold breach and remained active until conditions returned to normal. The Blynk dashboard widgets updated in real-time throughout all Wi-Fi connected testing periods. Push notifications received by the supervisor's device from the Blynk dashboard occurred within seconds after detection of any simulated threshold breach, confirming the end-to-end functionality of the alert system. As shown in Fig. 4, the Blynk dashboard widgets updated in real-time, displaying gas concentration at 1,000 PPM and radiation dose rate at 0.31 μSv/hr, consistent with expected ambient lab conditions.

E. Discussion

Technical goals have been completely reached. Testing done in a laboratory environment showed that the entire integrated system (which included MQ-2 gas sensor, GM tube for detecting radiation, local buzzer for alerts and Blynk for remote monitoring) performed reliably in all of its subsystems. The dual-alert architecture worked well to provide both users of the device (i.e., worker and supervisor) knowledge of a hazard, using only one low-priced wearable unit.

VI. Conclusion and Future Work

A. Conclusion

The presented design, construction and tested proof of concept for an IoT connected low cost Smart Safety Mask will be used by Workers at Landfills. The system integrates an MQ-2 Methane Sensor and a Geiger-Müller Radiation Detector with an ESP32 Microcontroller to create Local Alerts based on Real Time Thresholds via the Onboard Buzzer and Remote Supervisor Notifications through the Blynk Platform. All subsystems tested in the Prototype had the expected functionality and therefore creates a capability, being able to Monitor both Gas and Radiation as one Wearable, which currently does not exist as documented for this Worker Group.

B. Future Work

The next priority steps will be Field Testing at a working Landfill and adding CO, H_2S, and NH_3 gas detection using additional types of MQ Gas Sensors. Cellular (GSM) and GPS Tracking will need to be added to improve Monitoring since Landfills do not have Wireless (Wi-Fi) connections. This will require custom PCB design with specifications for a dust and moisture resistant enclosure. The Software Development will need enhancements to add Machine Learning (ML) Anomaly Detection to reduce False Positive Events, add Physiological Sensors (i.e. Pulse Oximeter), and allow Supervisors to view multiple Worker dashboards from a Central Source.

References

[1] P. Gopalka, P. Parikh, and P. Shah, "Design and Development of an IoT-Enabled Smart Air-Purifying and Monitoring Mask for Hazardous Industrial Environments," *Int. J. Adv. Res.*, vol. 13, no. 08, pp. 187–198, Aug. 2025. [Online]. Available: https://www.researchgate.net/publication/395132578

[2] J. Hyysalo, S. Dasanayake, J. Hannu, C. Schuss, M. Rajanen, T. Leppänen, D. Doermann, and J. Sauvola, "Smart Mask – Wearable IoT Solution for Improved Protection and Personal Health," *Internet of Things*, vol. 19, p. 100511, May 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2542660522000166

[3] L. M. Easterline et al., "Smart Air Monitoring with IoT-based MQ-2, MQ-7, MQ-8, and MQ-135 Sensors using NodeMCU ESP32," *Procedia Comput. Sci.*, vol. 245, pp. 815–824, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1877050924031168

[4] G. Karuna, R. R. Kumar, S. Gopaldas, V. Parvathaneni, and T. Lokesh, "Air Quality and Hazardous Gas Detection using IoT for Household and Industrial Areas," *E3S Web Conf.*, vol. 391, p. 01146, 2023. [Online].

https://doi.org/10.71058/jodac.v10i08a11

Available: https://www.e3s-conferences.org/articles/e3sconf/pdf/2023/28/e3sconf_icmed-icmpc2023_01146.pdf

[5] T. Veeramanikandasamy, S. Gokul Raj, A. Balamurugan, A. P. Ramesh, and Y. A. Syed Khadar, "IoT Based Real-time Air Quality Monitoring and Control System to Improve the Health and Safety of Industrial Workers," *Int. J. Innov. Technol. Explor. Eng.*, vol. 9, no. 4, pp. 1879–1884, Feb. 2020. [Online]. Available: https://www.researchgate.net/publication/339182264

[6] Agency for Toxic Substances and Disease Registry (ATSDR), "Landfill Gas Safety and Health Issues," *Landfill Gas Primer*, Ch. 3, U.S. Dept. of Health and Human Services, 2001. [Online]. Available: https://www.atsdr.cdc.gov/HAC/landfill/PDFs/Landfill_2001_ch3.pdf

[7] New York State Dept. of Health, "Important Things to Know About Landfill Gas," *Environmental Health*, 2021. [Online]. Available: https://www.health.ny.gov/environmental/outdoors/air/landfill_gas.htm

[8] Occupational Safety and Health Administration (OSHA), "Hydrogen Sulfide — Overview and Hazards," U.S. Dept. of Labor. [Online]. Available: https://www.osha.gov/hydrogen-sulfide

[9] S. E. Tshivhase, N. S. Mashau, T. Ngobeni, and D. U. Ramathuba, "Occupational Health and Safety Hazards among Solid Waste Handlers at a Selected Municipality South Africa," *Health SA Gesondheid*, vol. 27, Dec. 2022. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC9772716/

[10] A. Siddiqua, J. N. Hahladakis, and W. A. K. A. Al-Attiya, "An Overview of the Environmental Pollution and Health Effects Associated with Waste Landfilling and Open Dumping," *Environ. Sci. Pollut. Res.*, vol. 29, pp. 18127–18139, 2022. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC9399006/

[11] S. T. Imam and I. M. Rafizul, "Occupational Risks, Vulnerabilities, and Safety Challenges among Informal Waste Workers at the Open Disposal Site in Khulna City," *Int. J. Hyg. Environ. Health*, vol. 266, p. 114543, 2025. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S1438463925000252

[12] E. de Titto and A. Savino, "Human Health Impact of Municipal Solid Waste Mismanagement: A Review," *Adv. Environ. Eng. Res.*, vol. 5, no. 2, p. 014, 2024. [Online]. Available: https://www.lidsen.com/journals/aeer/aeer-05-02-014

[13] M. I. Ahmad, M. H. Ab. Rahim, R. Nordin, F. Mohamed, A. Abu-Samah, and N. F. Abdullah, "Ionizing Radiation Monitoring Technology at the Verge of Internet of Things," *Sensors*, vol. 21, no. 22, p. 7629, Nov. 2021. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC8619633/

[14] . Wang, X.-B. Tang, P. Gong, X. Huang, L.-S. Wen, Z.-Y. Han, and J.-P. He, "Design of a Portable Dose Rate Detector Based on a Double Geiger-Mueller Counter," *Nucl. Instrum. Methods Phys. Res. A*, vol. 879, pp. 250–257, 2018. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0168900217308367

[15] P. C. Aspetti, L. Martellucci, R. Quaranta, and G. Manenti, "Design for Enhanced Gamma Radiation Detection Prototype: A Comprehensive Approach," *Eur. Phys. J. Plus*, vol. 140, p. 273, Apr. 2025. [Online]. Available: https://link.springer.com/article/10.1140/epjp/s13360-025-06158-7

[16] R. K. Kodali, S. Yerroju, and B. Y. Krishna Yogi, "IoT Based Wearable Device for Workers in Industrial Scenarios," in *Proc. TENCON 2018 – IEEE Region 10 Conf.*, Jeju, South Korea, 2018, pp. 1–6. [Online]. Available: https://ieeexplore.ieee.org/document/8650187

[17] E. Svertoka, S. Saafi, A. Rusu-Casandra, R. Burget, I. Marghescu, J. Hosek, and A. Ometov, "Wearables for Industrial Work Safety: A Survey," *Sensors*, vol. 21, no. 11, p. 3844, Jun. 2021. [Online]. Available: https://www.mdpi.com/1424-8220/21/11/3844

[18] P. Battistoni, M. Sebillo, and G. Vitiello, "An IoT-Based Mobile System for Safety Monitoring of Lone Workers," *IoT*, vol. 2, no. 3, pp. 476–497, 2021. [Online]. Available: https://www.mdpi.com/2624-831X/2/3/24

[19] P. Jacko et al., "Design and Implementation of ESP32-Based IoT Devices," *Sensors*, vol. 23, no. 15, Jul. 2023. [Online]. Available: https://www.mdpi.com/1424-8220/23/15/6739

[20] N. Kržanović, K. Stanković, M. Živanović, M. Đaletić, and O. Ciraj-Bjelac, "Development and Testing of a Low Cost Radiation Protection Instrument Based on an Energy Compensated Geiger-Müller Tube," *Radiat.*

https://doi.org/10.71058/jodac.v10i08a11

Phys. Chem., vol. 164, p. 108358, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0969806X18312696